OUTBOARD FUEL SYSTEMS DIAGNOSIS

Let's begin by stating no two fuel systems are alike, even those in identical model boats. Boat fuel systems are unique in several ways that should really matter to service technicians. The majority of recreational boats do not have a fuel system engineered and tested by the same manufacturer, unlike most other forms of petrol powered transport, like your car, truck or light plane.

This means that various parts of the system were selected and fitted by the boat builder, the engine maker and the engine installer. Often this is the retailer, but it could also be the consumer. There is plenty of opportunity for errors in part selection and fitting here, so good technicians must be aware of the requirements for a fuel system that matches the engine and is safe.

Any discussion on fuel systems should start with stressing the safety aspects of onboard fuel systems. Boats and planes are unique in that any sort of fuel leak is usually retained inside the vehicle, or the hull in the case of boats. This means that evaporating fuel can reach an explosive mixture with the surrounding air, inside an enclosed space. Any sort of ignition can then cause a real disaster.

The sketch in figure 1 provides an overview of the basic requirements for a safe fuel system.

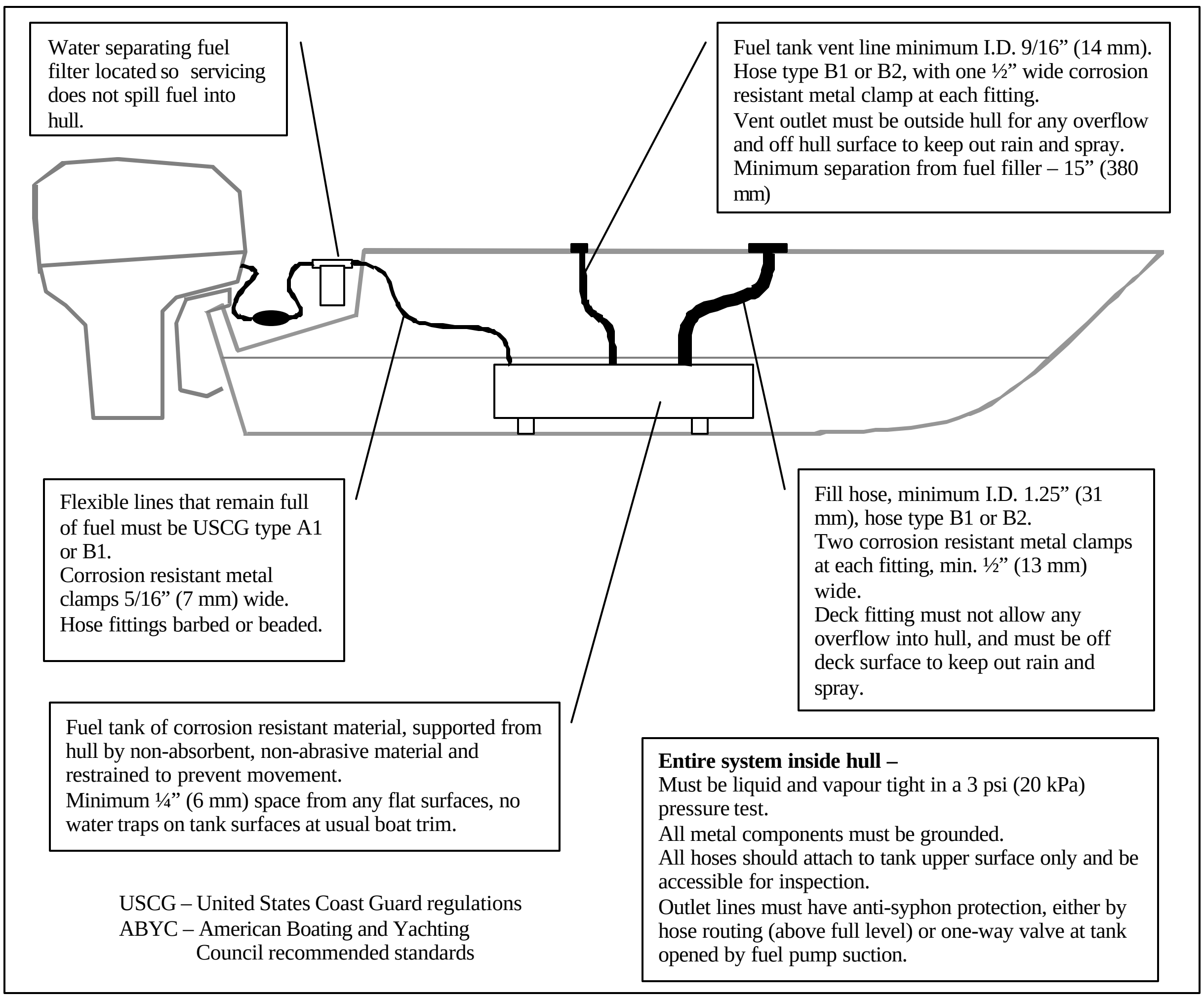


Figure 1

Now the job of the fuel system does not sound too difficult. Lift fuel out of the boat tank, supply it to the carburetors or injection system for distribution to the cylinders. Sounds simple enough, but the engine's actual requirements need to be more specific if we are to diagnose the system.

Outboard engines require –

- liquid fuel (no vapour or air mixed with the fuel) and,
- at a supply rate that exceeds the engine's demand.

Liquid fuel is required because that's what carburetors and injection systems are designed to meter correctly. Adding some vapour or a little air may not seem to be a problem, but sooner or later it will be. Carburetor engines have float chambers that automatically separate the air and vapour from the liquid, which would appear to make carburetor engines immune from this sort of problem, but not so. As soon as a vapour or air bubble gets large enough to fill the fuel pump's main chamber it will no longer pump fuel. This is because the air or vapour is very compressible, so the fuel pump diaphragm can move full stroke without causing the outlet valves to open. When that happens we have "vapour lock" and no fuel flows.

Even if the air or vapour bubbles are small and don't cause to fuel pump to stop, they will increase the speed of the fuel pump. Fuel pump diaphragms stroke at the speed it takes to keep the carburetor float chambers full. Any air or vapour in the fuel takes up space that would otherwise be liquid fuel, but when it gets to the float chamber is lost out the vent, so the fuel pump must stroke more often to keep up the supply of liquid fuel. On engines with combined fuel and oil pumps, any pump speed increase results in more oil, leading to smoky operation and even fouled spark plugs.

What causes vapour and air leaks? Well the air leaks have obvious, but not always visible causes. Bad fitting connections and damaged flexible hoses being the most common. Vapour has two main causes. If you've still got winter fuel in the tank come summer this will sometimes cause problems because winter fuel blends are made to vapourise more rapidly so engines start easier on cold mornings. That can then result in too much vapour in hot weather. The other main cause of vapour is high vacuum in the fuel lines. Any restriction to flow will result in a partial vacuum forming and fuel vapourises much more rapidly as the pressure on it decreases.

There is however a rather simple test for supply problems. We simply insert a vacuum gauge in the supply line just before the fuel pump, some clear hose also at the fuel pump inlet and a pressure gauge at fuel pump outlet. The sketch in figure 2 shows a typical V4 outboard fuel system. With gauges inserted (using Tee fittings) and some clear hose, it is then just a matter of operating the motor at maximum fuel flow (wide open throttle) and note the readings.

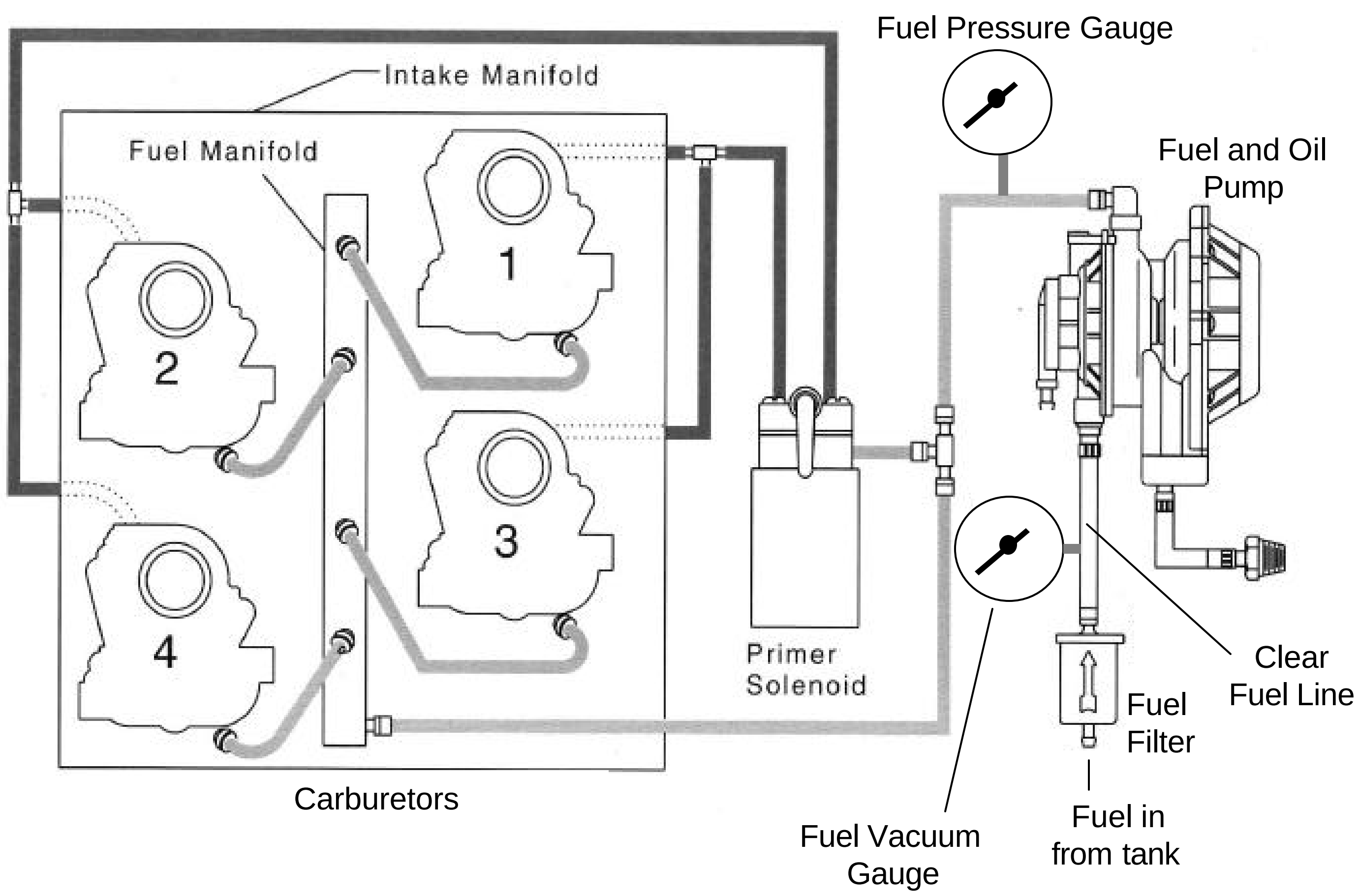


Figure 2

The pressure and vacuum readings to expect will vary with make and models. Common readings with many large outboards are a minimum of 3 psi (20 kPa) fuel pressure and a maximum of 4 inches of mercury (in HG) (100 mm HG) fuel line vacuum, at maximum rpm.

The following table explains the combinations you are likely to see -

Fuel Pressure	Fuel Vacuum	Bubbles in clear line?	Comment
Over 3 psi (20 kPa)	Below 4 in HG (100 mm HG)	no	High pressure, Low vacuum and no bubbles = No problem, system OK
Below 3 psi (20 kPa)	Below 4 in HG (100 mm HG)	no	Low pressure, Low vacuum and no bubbles = Fuel Pump problem
Below 3 psi (20 kPa)	Over 4 in HG (100 mm HG)	Yes	Low pressure, High vacuum and bubbles visible = Restriction to supply, vapour bubbles forming.
Below 3 psi (20 kPa)	Below 4 in HG (100 mm HG)	Yes	Low pressure, Low vacuum and bubbles visible = Air leak into fuel supply line.

As you can see, both pressure and vacuum tests, with a clear hose, are really necessary to test the whole supply system for all likely problems. Fuel pressures over the minimum specified at full throttle show that the system can flow in excess of the engine's demand. This is essential to avoid the possibility of lean fuel fuel/air mixtures at high power outputs that can cause detonation and lead to piston seizure.

Most common problem cause? Undersize fuel lines or fittings and air leaks. As a general rule, all fuel lines need to be a minimum of 5/16" (8 mm) ID up to 4 cylinder or about 130 HP engines, and 3/8" (10 mm) ID above that. In addition all hose fittings (hose tails, tees, pick-up tubes etc.) need to be a minimum of ¼" (6 mm) ID.   Airline fittings look the same on the outside but have much smaller ID than dedicated marine fuel fittings, so be on the lookout for these! Airline fittings need to deal with much higher pressures than fuel lines, so they have much thicker wall sections.

Air leaks are possible in many places, both at fittings and at random places along the flexible line. One simple misconception here that an air leak will also leak fuel so you can easily see them. This is definitely not true, as air will leak in through holes too small for a liquid to get through, or for us to see them. Only the vacuum test really show up air leaks.

Once your fuel supply system tests OK, then the next step in a fuel system diagnosis is how fuel is distributed to the cylinders. Step one – do all carburetors or injectors get an equal chance at the fuel supplied? Here the pressure gauge can be used again, this time in the supply line as close as possible to the individual carburetor or injector. Most larger outboards have one carburetor or injector per cylinder so problems in the plumbing can cause individual cylinder dramas. Pressure reading at each carburetor or injector inlet should be the same as you measured at the fuel pump outlet and equal for all cylinders. Restrictions caused by twisted or kinked hoses, and damaged plastic fittings are not unknown and can lead to fuel mixtures leaning out at the worst possible time, at maximum power.

If the supply pressures are the same to each carburetor or injector, then it's time to compare how they meter fuel to each cylinder. Unfortunately there's no simple instrument or gauge we can just plug in here, but there are several very effective tests. Most outboard carburetors have three metering systems or circuits that overlap each other throughout the rpm range. The idle system is the primary fuel system when the throttles are closed and for just off idle, then the intermediate system takes over until the rpm is high enough for air flow in the venturi to pull fuel through the main or high speed system. This occurs some where about 2000-2500 rpm on most models.

There are two simple diagnosis methods with carburetors, enrichment and spray pattern comparison.

Enrichment means making individual cylinders go richer and observing the engine's response. You can do this various ways, squirt some fuel into the carburetor throat from a plastic squeeze bottle or block the air bleed jet for the carburetor circuit under test. One of three results is possible –

Engine speed increases -	This indicates that circuit was lean and needs to be richer.
Engine speed decreases -	This indicates that circuit is now too rich and is very likely OK.
Engine speed remains unchanged -	This indicates the engine is not running on this cylinder, but it's not because of a lack of fuel.

Caution – This test is not very effective with direct injection engines. They have large amounts of air flowing through the throttles, even at idle, and control the idle speed by the amount of fuel injected. If you squirt more fuel in the engine will always run faster. This test might help you find a dead cylinder, but most of the new direct injection technology engines have easier ways to do this, like using a computer.

Just sticking your fingers into a carburetor throat and restricting the air flow is also very easy to do, but I caution against this because it provides little or no control over how much enrichment is provided, so it's real easy to drown that cylinder and get the wrong impression. You need to be able to add only a little fuel, note the result, try a bit more, note the result, and so on.

Most outboard motors have a box like device over the carburetor air inlets that is usually called an air silencer. On some engines the airflow is somewhat restrictive to further reduce noise getting out, but that means the air silencer is then part of the carburetor calibration. That is if you leave it off the motor goes lean at higher speeds. If you are testing for a problem at lower speeds, leaving the air silencer off is usually OK, but at high speed you can get into trouble. On these models to get individual cylinders to go rich you can run several temporary small diameter tubes in through the air intakes in the silencer and secure to the carburetor intakes. Another way is to do some temporary plumbing using the cold start primer hoses which are often outside the air silencer and therefore easier to get to.

The spray pattern comparison method means using a timing (Strobe) light to view the fuel spray as it enters the air in the carburetor throat. On two stroke engines this is quite easy to do because when the spark plug is being fired the piston is close to top dead centre. This is also the time when vacuum in the crankcase is close to maximum, so the leaf valves will be open and fuel/air mixture entering the crankcase. Pointing the timing light into the carburetor throat illuminates the fuel nozzles and the rapid strobe flash "suspends" the fuel flow pattern so you can see it. All you need to do then is move the timing light from cylinder to cylinder and compare the flows.

Once you feel you've isolated the problem to a particular carburetor, resist the urge to rip it apart throw a repair kit at it. Just like when we were discussing supply lines above, air leaks and restrictions can be near impossible to see and if they are caused by a warped surface or leaking pressed together joint, then most likely you won't have fixed it with a repair kit. One of the best ways to diagnose individual carburetor circuits is to flow liquid through them with a syringe or small plastic squeeze bottle. You can then ensure that circuit only flows where it is supposed to. Any time you have a carburetor apart, especially if you're searching for a problem, it's a good idea to seal all pressed together joints with a drop or two of Loctite 390 "Wick in". It's very good at curing small air leaks that are impossible to see.

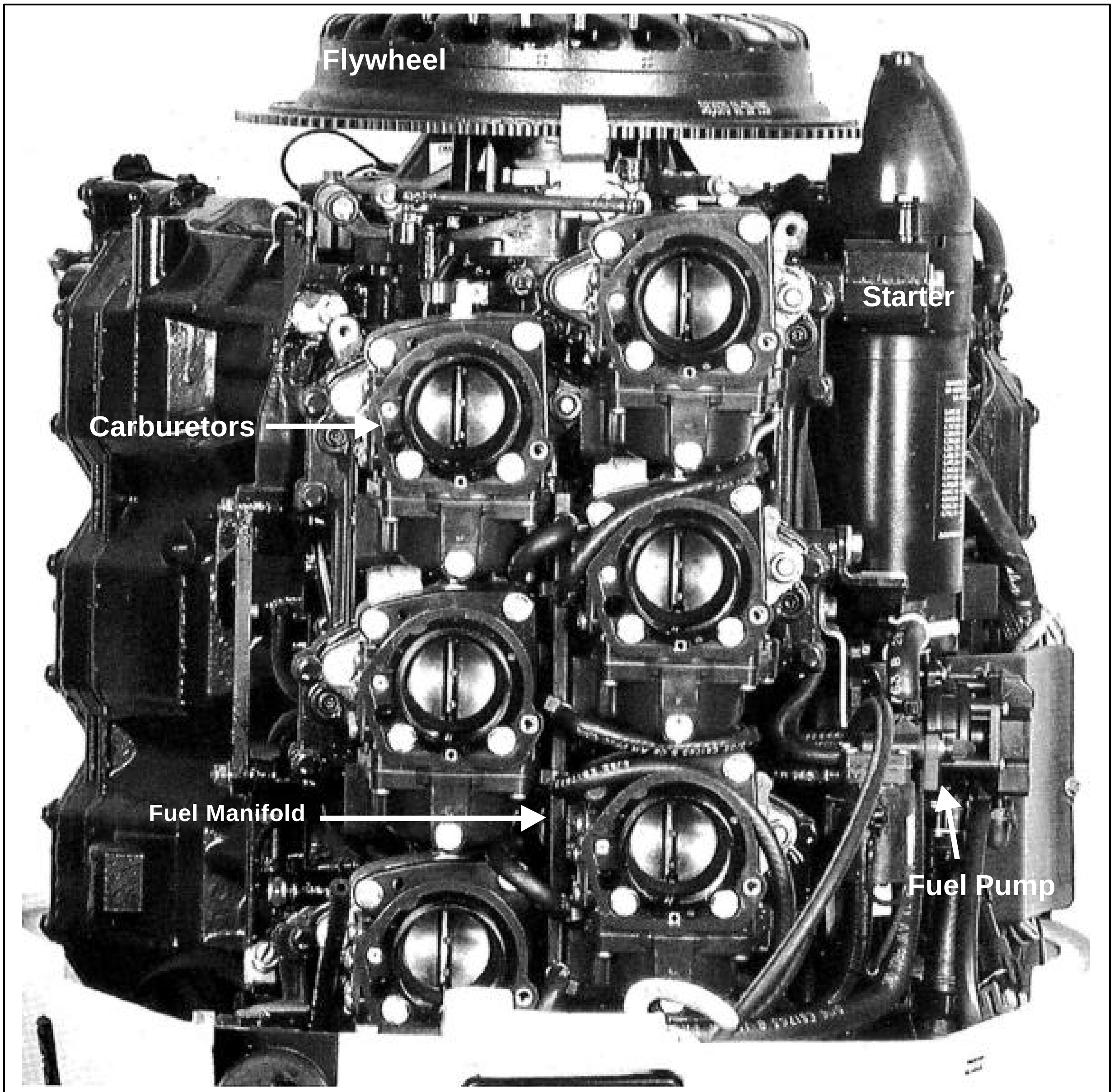
The last trouble shooting technique that works well on multi-cylinder engines is jet changing. Most outboard carburetors are not very complicated and easy to get at, so richening a cylinder (or several) with larger fuel jets (or smaller air bleed jets) is not as hard as it sounds, and you can a little or lot then test it for as long as you like.

Case Study.

A 250 HP outboard suddenly seized pistons number 5 and 6, after about 2 years of use. Damaged pistons looked like the cause was heat related, but there were no other obvious signs like burnt paintwork or melted plastic parts to indicate a cooling system problem. Internally the engine was fine, except for the two slightly damaged bores. A visual inspection showed no obvious cause, so that means further testing has to wait until its repaired and running again.

With all cylinders fixed and back running again the technician tested cooling system, ignition system including timing to all cylinders and ensured all engine adjustments were OK. No problem was found. Then it was time to test the fuel system. Pressure and vacuum gauges, with a clear hose, were attached. First high speed test showed a maximum of 2 psi (14 kPa) and 2.5 in. HG (65 mm HG) vacuum, and no bubbles. This engine needs a minimum of 3 psi at wide open throttle, so something is not right here. As there were no air or vapour bubbles visible the suspicion falls on the fuel pumps, this engine having two crankcase pulse driven pumps plumbed in parallel. On a bench test one pump showed much lower output than the other so it was replaced and the tests repeated.

Fuel pressure came up to 4.5 psi (33 kPa) and vacuum came up to 3.5 in HG (90 mm HG). A post mortem on the faulty pump showed a defective valve. The engine has since run many hours over several years with no further problems. Lack of fuel pressure had caused piston temperatures to rise to the point of seizure. Why did the problem only occur in cylinders 5 and 6 and not any of the others? All multi-cylinder engines have different pressures and temperatures in the cylinders at any one due to differences like compression ratio, water flow around the cylinders, shape of the exhaust manifold, and so on. With this engine 5 & 6 just happened to be the warmer cylinders and therefore reached damage point first.



The business end of a 3 litre, 90 degree V6, 250 HP outboard fuel system, with the air silencer removed.